The emission impact of the innovative grate shape in the fireplace stove and comparison with the car

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Abstract. The study aims to research the emission impact of innovative grate shape in the fireplace stove. According to environmental compliance, decisions from these results and the subsequent development of the grate and the combustion chamber are the key for all activities. The second part of the research compares emissions from the fireplace stove combustion with car emissions.

Keywords. Fireplace stove; emission; innovation; grate.

1 Introduction

Purpose of the study is research of the emission impact of the innovation grate shape in the fireplace stove. The paper also handles comparisons between emissions from the fireplace stove and car emissions. Very important is determine significance in terms of polluting the environment, specially CO, CO_2 a NO_x. Change the classic shape of grooves in the grate is one of the main factor for amount of pollutants and better combustion.

2 Materials and methods

The scientific examine summary shows very same shapes of grooves in grates of fireplace stoves portfolio. Simply, there exist rectangular holes and few more modifications. Conventional fireplace stoves can be regulated with primary and secondary air, which are controlled manually or in combination with an automatic control of flue gas purity level [1]. In a modern households (passive houses), the air supply is realized by a central air (Fig. 1). This is mainly due to the fact, that the supply of oxygen to the room without direct ventilation (open window / door) is not possible any more. In the hearth of the fireplace itself the air must be optimally distributed to supply a sufficient amount of oxygen to the individual combustion phases:

- primary air ... use on start of the burning, this air is coming under the grate
- secondary air ... this one is use for cleaning glass

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- tertiary ... for more better combustion, because it exists no ideal combustion, it must be supplied larger amount of combustion air

Combustion products are flue gases. With perfect combustion, these are carbon dioxide CO_2 and sulfur dioxide SO_2, then water H_2O and nitrogen oxides NO_x, which are the priority pollutants [2]. In the imperfect combustion (there is no ideal burning with small amount of oxygen supplied or rapid cooling) carbon monoxide CO is formed, with connection small amount energy (1/3 ideal energy). In this process exist the organic gaseous carbon OGC (hydrocarbon compounds). Part of them are soot and they emit to the air in the form of particulate matter (PM).

2.1 Distribution of the air

From these reasons we have to control of the combustion process. Only so, we can approach closer to ideal burning. In the ordinary open fire it is not possible. However, producers can use solution with optimal divide the air into the individually phase of burning.

- 100°C water evaporation
- 150°C start of release of volatile combustibles (EN 15357)
- 200 ÷ 250°C first burning combustible components
- 450°C ignites hydrogen and hydrocarbons (characterized by sharp rise in temperature)
- 500°C ignition of a combustible solid

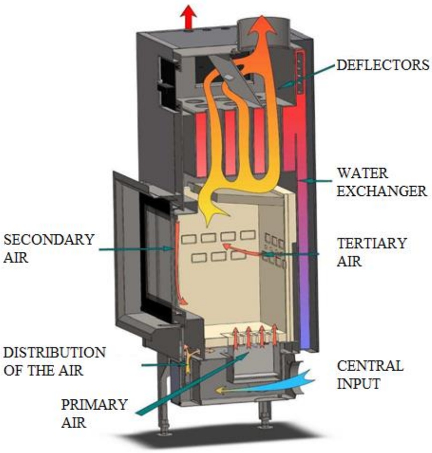


Fig. 1 Air ways in the fireplace stove

2.2 Calculation of the fuel

When the air is introduced into the combustion chamber, it is necessary to deal with the required fuel dose and its calculation, which is then governed by the formula (1):

$$B_{fl} = \frac{360000.P_n.t_b}{H_u.\eta} \quad (1)$$

, where
B_{fl} mass of fuel [kg]
H_u heating value of testing fuel [kJ/kg]
η efficiency according EN 13229 or value from official producer [%]
P_n nominal thermal performance [kW]
t_b shortest delivery time interval of the fuel or period time of the combustion from official producer [h]
The heating value of tree species are in the table (Tab. 1).

Tab.1 The heating value

tree species	heating value		
	MJ/kg	MJ/pm	MJ/rm
acacia	12,7	11850,0	8030,0
alder	12,9	8260,0	5550,0
ash	12,7	11010,0	7450,0
beech	12,5	10830,0	7320,0
birch	13,5	10550,0	7100,0
fir	14,0	8040,0	5800,0
hornbeam	12,1	10970,0	7400,0
larch	13,4	9720,0	7040,0
oak	13,2	11050,0	7430,0
pine	13,6	9250,0	6730,0
poplar	12,3	6540,0	4440,0
spruce	13,1	7350,0	5440,0
willow	12,8	8490,0	5740,0

Source: Database of the ABX, spol. s r. o.

2.3 Research subject

Classic grate with rectangular holes is ordinary grate shape, testing shape of holes is hexagonal (Fig. 2.).

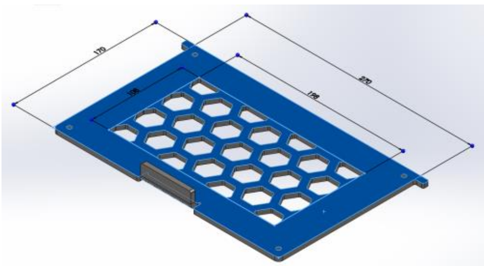


Fig. 2 Hexagonal shape of holes

Two configurations were made for research needs. They have 10,2mm dimension between minimum distance of inner hexagon and 15,6mm (Fig. 3).

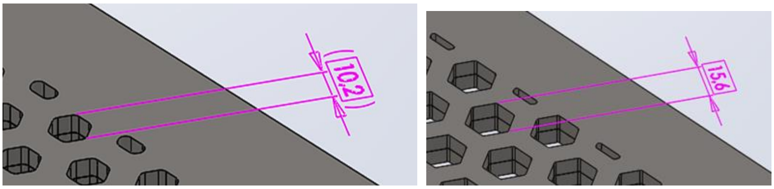


Fig. 3 Configurations of the grate shape

Semi-finished products were made according 3D model from Solidworks 2019. These were used for combustion chamber completation and for preparing of the operational test. Input material was steel DD11 of thickness t=5mm (Fig. 4). Two sheetmetal parts were made for each configuration. For best aproximation with real standards were welded together and so simulated thickness of the original part from cast iron.

Fig. 4 The real semi-finished of the grate

An imposing factor is the size of space for primary air coming out. It has the main effects on the test. However, first is very important to do the current test with limited to a minimum primary air burning with the assistance of full secondary air, which uses sides and the air pass above the grate also. The ratio of the pass content air from configurations is in the figure (Fig. 5). The grate type (I-III) is on the X-axis, and Y-axis is the area in mm^2.

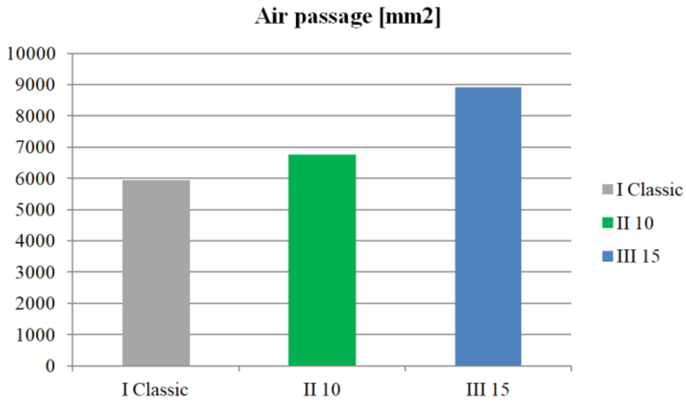


Fig. 5 The air passages

, where exact numbers are
S_I=5932,4 mm^2
S_{II}=6757,43 mm^2
S_{III}=8920,17 mm^2

2.4 The Laboratory

The measurement itself took place in sophisticated laboratory (Fig. 6) in ABX company. The conditions were the same as in the certified laboratory.

Fig. 6 The laboratory of emissions measurement

Responsible laboratory workers must perfect planning because laboratory time is busy and expensive. The best way to do this is to plan tasks according to the SMART system. Every single test summarized phases. The first one is the installation of the grate into the combustion chamber. The second is ignition and outrage, and the next is adding the fuel. When flames are not visible test ends. In the chamber are embers only in this time. All these phases together are one period. It takes approx 0,75h. The type of fuel is from a renewable sustainability source [3]. It was considered wood briquettes in this study. Lab staff records in a table measures dimensions (Fig. 7) and mass weights. Idea divides the test into 1 (I) classic + 2 innovative grates (Fig 3). Inside hexagon with dimension 10,2mm (II); 15,6mm (III). The usual classic grate is like the standard for comparison state.

Fig. 7 Measurement of the briquette

The study needs to build a physical prototype, install the fireplace stove with the name Atrium 7 from ABX company in the Czech Republic and test grates in a unique laboratory. The following figure (Fig. 8) is photography with natural combustion, thermo camera vision and monitoring screening.

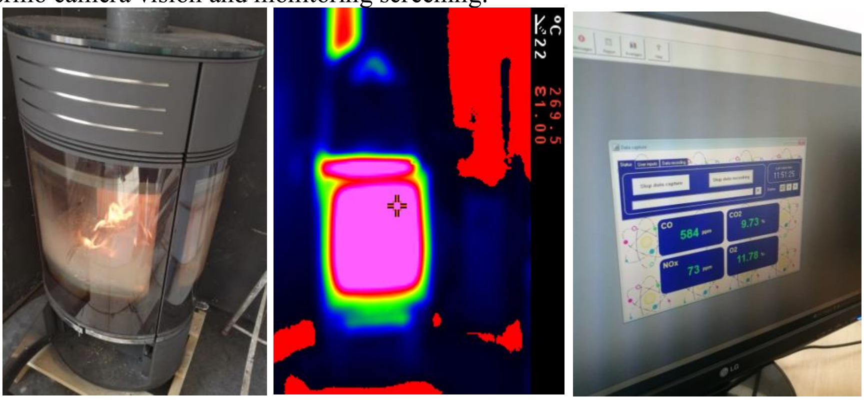


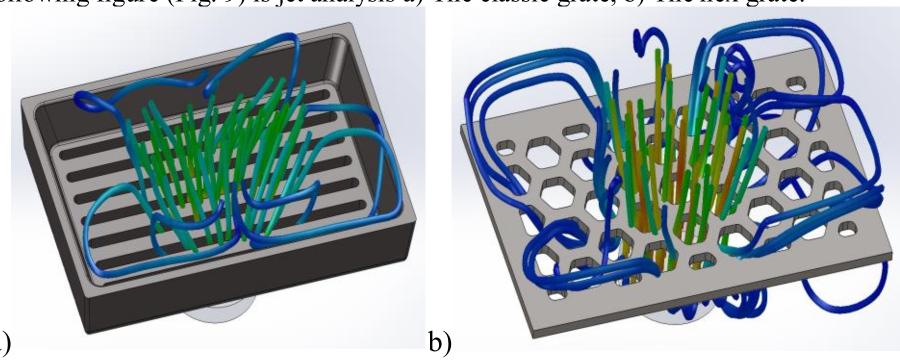
Fig. 8 The natural test in the unique laboratory

The main measurement:

- thermal performance [kW]
- fuel consumption [kg/hod]
- efficiency [%]
- temperature of the flue gas [°C]
- mass flow of the flue gas [g/s]
- concentration CO, CO_2, NO_x, OGC and PM at 13% O_2 [mg/Nm3]
- environment temperature
- compliance with standards (DIN, EN)

2.5 FEM analysis

The modern method is CFD analysis. Engineers can predict the emission of the fireplace stove.
Initial and boundary conditions of the FEM model:
input (pressure p_{in}=101325 Pa; temperature T_{in}=293,2 K (Common Temperature Reference Points)
output (pressure p_{out}=101315 Pa; temperature T_{out}=293,2 K)
Notice: Standard temperature and pressure (STP) are technical standard sets of conditions for experimental measurements to allow comparisons between different data sets.
Software used for simulations was FloXpress for Solidworks Premium 2019 SP 5.0. This software was analyzed flew of the air passages around and thru the grate. In the following figure (Fig. 9) is jet analysis a) The classic grate, b) The hex grate.



a) b)

Fig. 9 CFD jet analysis

3 Results and discussions

The heating value of tree species are in the table (Tab. 2).

Tab. 2. Configuration I÷III results

		I	II	III	Average
Fuel consumption	kg/h	2,72	2,82	3,56	3,03
Mass of the fuel	kg	2,04	2,02	2,02	2,03
Time of combustion period	h	0,75	0,72	0,57	0,68
Thermal performance	kW	11,6	12,0	15,2	12,9
Temperature of input air	°C	26	25	26	26
Chimney lift	Pa	12	12	12	12
Average flue gases temperature	°C	251	289	303	281
CO2	%	8,23	7,48	8,48	8,06
CO (O2 = 13%)	%	0,0748	0,1204	0,0897	0,0950
CO (O2 = 13%)	mg/Nm^3	935	1504	1122	1187
CO (O2 = 0%)	mg/MJ	650	1047	780	826
NOx (O2 = 13%)	mg/Nm^3	135	128	127	130
NOx (O2 = 0%)	mg/MJ	94	89	88	90
OGC (O2 = 13%)	mg/Nm^3	46	130	33	70
OGC (O2 = 0%)	mg/MJ	32	90	23	48
Chimney loss	%	20,98	26,80	25,29	24,4
Efficiency	%	77,91	71,74	73,48	74,4
Summary of the thermal performance	kW	9,04	8,61	11,17	9,6
Uncertainty of the thermal performance	kW	0,38	0,36	0,47	0,40
Nominal thermal performance	kW	9,0	9,0	9,0	9,0
Mass flow of the dry flue gases	g/s	9,7	11,0	12,3	11,0
Dust (O2 = 13%)	mg/Nm^3	39,0	47,0	37,0	41,0
Dust (O2 = 0%)	mg/MJ	27,4	32,7	25,9	28,7
Flue gas temperature above throat	°C	365	341	364	357

The study can say that the effect of changing the shape of the air passages using only the secondary air is not very dramatic. The chimney loss increased above the value of 20.98%. The value of the loss due to gas firing is also higher, which the standards do not follow. The obtained good result was with the NOx value, which reduced below 94 mg / Nm3 in all cases. Graph (Fig. 10) brings graphical processing of results.

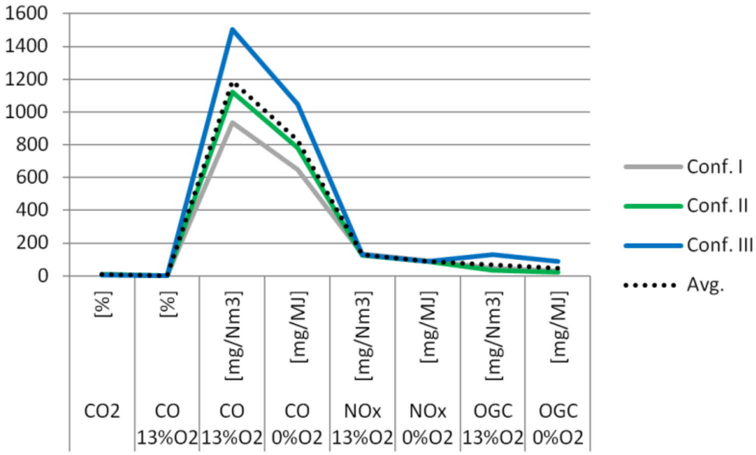


Fig. 10 Emission results of the fireplace stove

Results of passenger car measurements from certified laboratory (Jablonec nad Nisou city - DEKRA) are in the table (Tab. 3).

Tab. 3. Passengers car emissions results

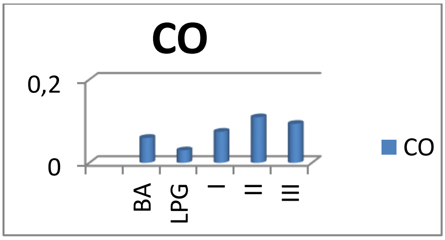
ŠKODA 1992	Fuel: Gasoline (BA)					
	Status	n [min^{-1}]	CO [%]	CO_2 [%]	HC [ppm]	Lambda [-]
	Measured	805	0,18	10,1	950	1,383
	Limit	750-850	max. 1,50	-	max 500	0-0
	Measured	2776	6,14	11,0	467	0,835
	Limit	2500-2800	max 2,50	-	max 500	0-0

ŠKODA 2005	Fuel: Gasoline (BA)					
	Status	n [min^{-1}]	CO [%]	CO_2 [%]	HC [ppm]	Lambda [-]
	Measured	682	0,06	15,3	176	0,995
	Limit	650-850	max 0,50	-	-	0-0
	Measured	2440	0,13	15,4	79	0,998
	Limit	2400-2600	max. 0,30	-	-	0,970-1,030

ŠKODA 2005	Fuel: LPG					
	Status	n [min^{-1}]	CO [%]	CO_2 [%]	HC [ppm]	Lambda [-]
	Measured	682	0,03	14,0	134	0,995
	Limit	650-850	max. 0,50	-	-	0-0
	Measured	2440	0,12	13,9	97	0,995
	Limit	2400-2600	max. 0,30	-	-	0,970-1,030

KIA 2018	Fuel: Gasoline (BA)					
	Status	n [min^{-1}]	CO [%]	CO_2 [%]	HC [ppm]	Lambda [-]
	Measured	657	0,00	14,7	6	1,007
	Limit	560-760	max. 0,30	-	-	0-0
	Measured	2839	0,00	14,6	4	1,011
	Limit	2500-3000	max. 0,10	-	-	0,970-1,030

When comparing passenger car emissions, the research counts on a sample of ordinary ŠKODA OCTAVIA cars (2005). The values of the fireplace stove measurements show that the monitored fireplace stoves burden the environment more in terms of CO emissions. This result is valid only in the state when the car is not moving or in the idle speed mode of 682 min-1 (Fig. 11 a). When the model car's speed increased to 2600 min-1 (Fig. 11 b), it exceeded the value of CO in the ratio of best to worst result by 42%.

a)


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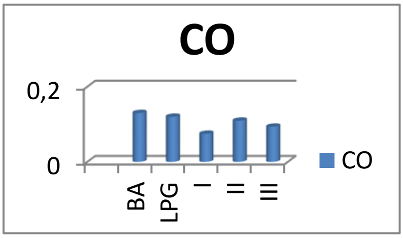

Fig. 11 Graph comparing the results of CO emissions of passenger cars and fireplaces (Fig. 9 a) speeds 657 min^{-1} to 805 min^{-1}, (Fig. 9 b) speeds 2600 min^{-1}

The following graph (Fig. 12) compares the environmental burden of CO_2 emissions. Measurements have shown no significant difference in CO_2 emissions between the car at speeds of 682 rpm and 2600 rpm. The excess of the environmental load by CO_2 emissions by the car is observable from the values.

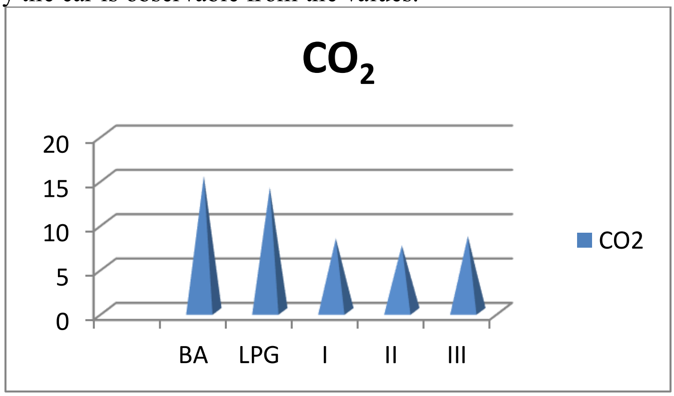

Fig. 12 Graph comparing the results of CO_2 emissions from passenger cars and fireplaces

4 Conclusions

The study's conclusion is the recommendation to test the grids of fireplaces with a higher ratio of primary air. Grate II achieves the best results with secondary air in the area of measured NO_x values.

When comparing the emissions of fireplaces and cars, passenger cars with internal combustion engines have a more significant burden on the environment.

Essential things are better combustion, sustainability of the planet and care about customers and end-users.

Nomenclature

ABX	Specialized Company for Fireplace Stoves in the Czech Republic
CFD	Computational Fluid Dynamics
DD11	Steel with Yield Strength 220MPa and Thermal Expansion 1,3e-05 K^{-1}
DEKRA	The Laboratory for Emission Measurement
DIN, EN	The European Standard
FEM	Finite Element Method
HC	HydroCarbons [ppm]
n	The Round of Engine [rpm or min^{-1}]
SP	Service Pack

Acknowledgment(s)

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